Mechanisms of temperature-dependent swimming: the importance of physics, physiology and body size in determining protist swimming speed

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Abstract: Body temperatures and thus physiological rates of poikilothermic organisms are determined by environmental temperature. The power an organism has available for swimming is largely dependent on physiological rates and thus body temperature. However, retarding forces such as drag are contingent on the temperature-dependent physical properties of water and on an organism's size. Consequently, the swimming ability of poikilotherms is highly temperature dependent. The importance of the temperaturedependent physical properties of water (e.g. viscosity) in determining swimming speed is poorly understood. Here we propose a semi-mechanistic model to describe how biological rates, size and the physics of the environment contribute to the temperature dependency of microbial swimming speed. Data on the swimming speed and size of a predatory protist and its protist prey were collected and used to test our model. Data were collected by manipulating both the temperature and the viscosity (independently of temperature) of the organism's environment. Protists were either cultured in their test environment (for several generations) or rapidly exposed to their test environment to assess their ability to adapt or acclimate to treatments. Both biological rates and the physics of the environment were predicted to and observed to contribute to the swimming speed of protists. Body size was not temperature dependent, and protists expressed some ability to acclimate to changes in either temperature or viscosity. Overall, using our parameter estimates and novel model, we are able to suggest that 30 to 40% (depending on species) of the response in swimming speed associated with a reduction in temperature from 20 to 5°C is due to viscosity. Because encounter rates between protist predators and their prey are determined by swimming speed, temperature- and viscosity-dependent swimming speeds are likely to result in temperature- and viscosity-dependent trophic interactions.

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Table S1. Summary of the probability of significance of a linear model on the temperature dependency of protist size

Parameter	d.f.	*F*	*P*	Species	Temperature variable	Viscosity variable	Acclimated
Temperature	1		0.42	*Didinium nasutum*	Yes	Yes	Yes
Temperature^2	1		0.9				
Error	9						
Temperature	1	0.91	0.36	*Didinium nasutum*	No	Yes	Yes
Temperature^2	1	0.14	0.71				
Error	15						
Temperature	1	0.0046	0.95	*Didinium nasutum*	Yes	Yes	No
Temperature^2	1	1.2	0.31				
Error	9						
Temperature	1	0.26	0.62	*Didinium nasutum*	No	Yes	No
Temperature^2	1	0.2	0.66				
Error	15						
Temperature	1	1.2	0.31	*Colpidium striatum*	Yes	Yes	Yes
Temperature^2	1	0.49	0.5				
Error	9						
Temperature	1	1.5	0.24	*Colpidium striatum*	No	Yes	Yes
Temperature^2	1	0.86	0.37				
Error	15						
Temperature	1	0.63	0.81	*Colpidium striatum*	Yes	Yes	No
Temperature^2	1	4.4	0.064				
Error	9						
Temperature	1	4.6	0.049	*Colpidium striatum*	No	Yes	No
Temperature^2	1	0.63	0.44				
Error	15						

Model structure and interpretation are detailed in the text.